Mining *CosmicGold* in the 2020s with Large Scale Structure Surveys

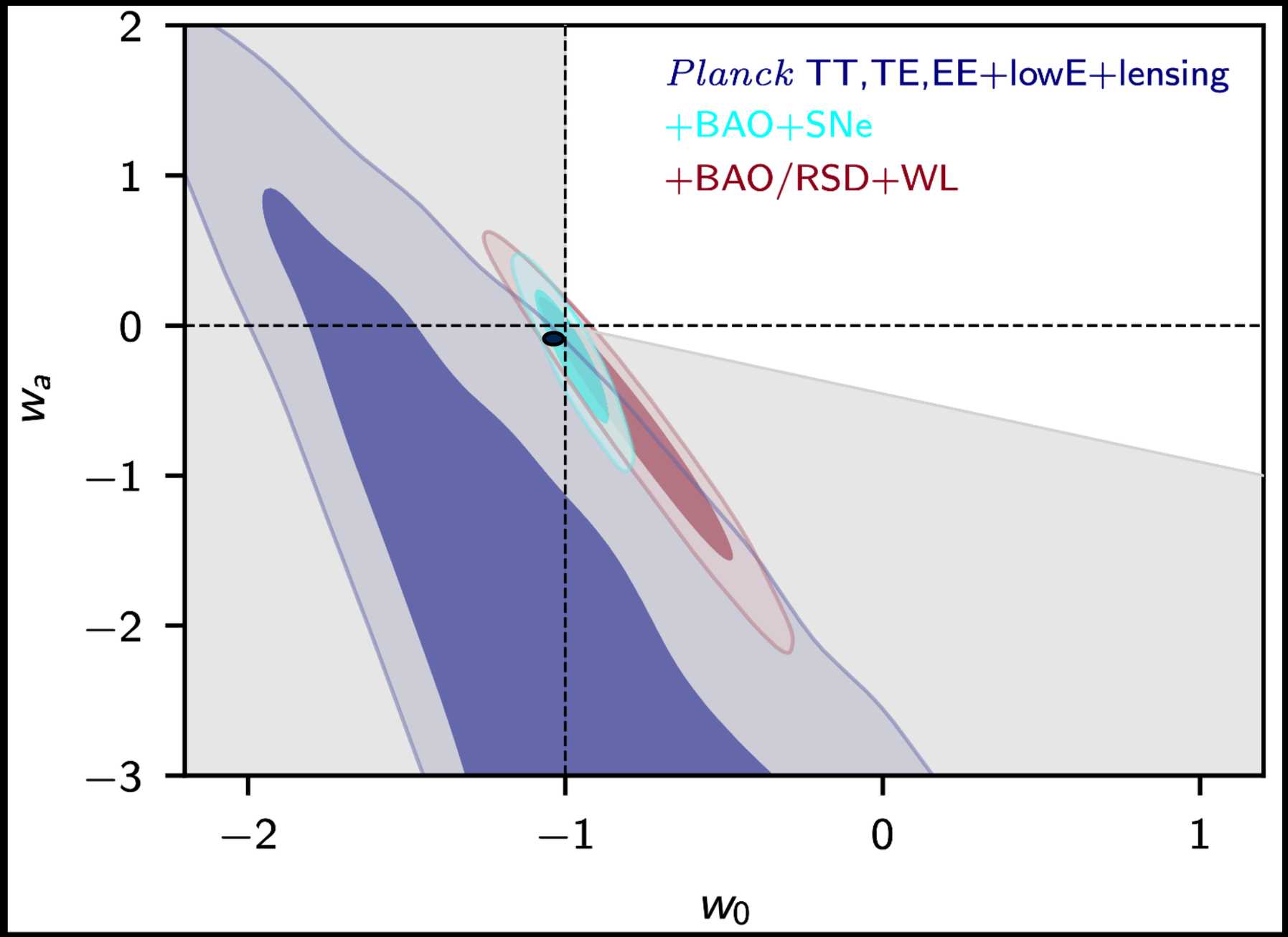
Olivier Doré
Jet Propulsion Laboratory
Caltech

Image Credit: Illustris TNG

http://spherex.caltech.edu
http://wfirst.hls-cosmology.org

SPHEREx Team
WFIRST Cosmology High Latitude Survey Team

DARK ENERGY DRIVES THE EXPANSION RATE...



Planck 2018 VI

LSS SURVEYS OF THE NEXT DECADE

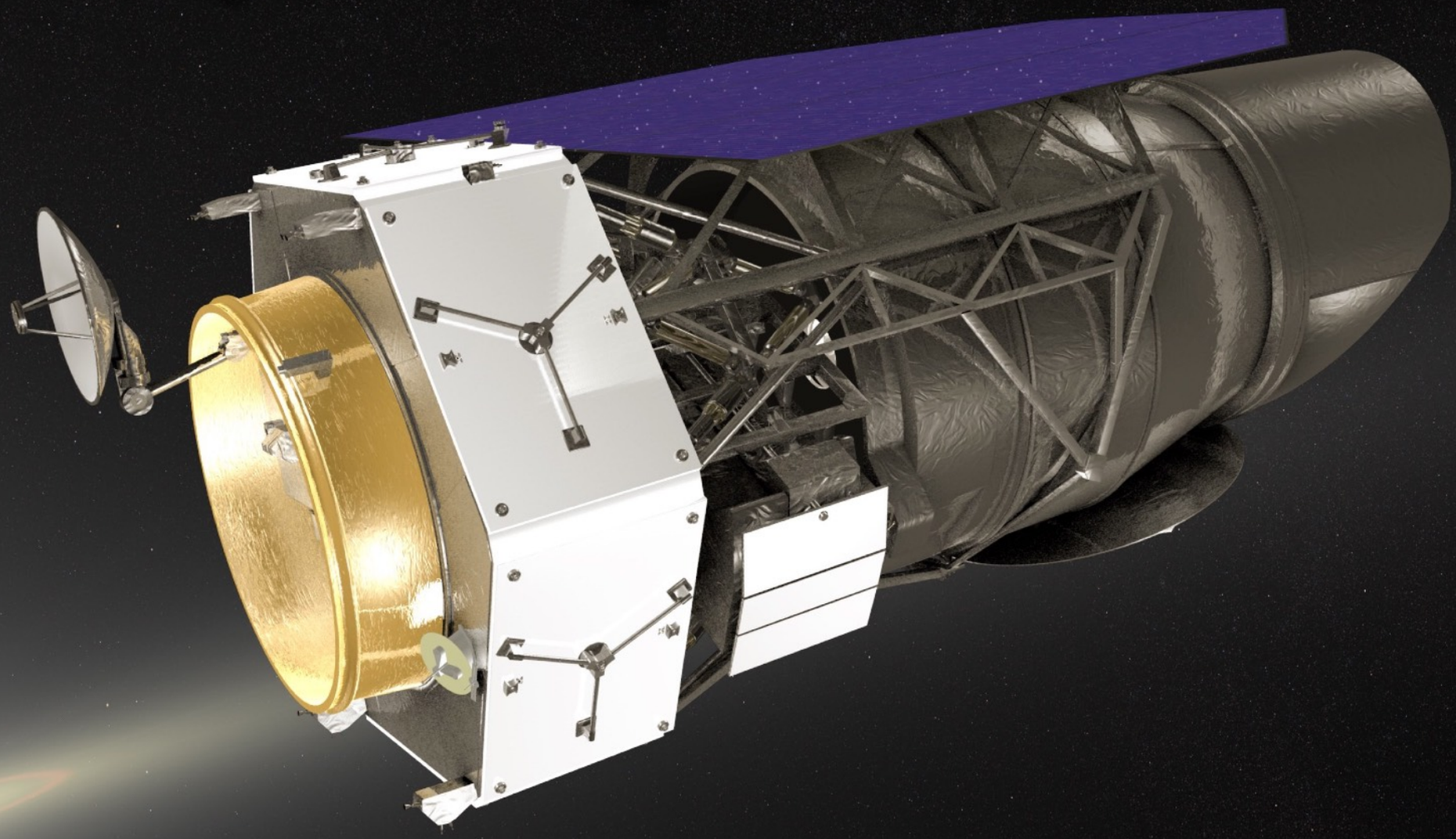
- DESI (BAO, RSD)
- LSST (WL, SNe, BAO w/ photo-z, Cl)
- Euclid (WL, BAO, RSD, Cl)
- SPHEREx (GC)
- WFIRST (WL, BAO, RSD, SNe, Cl)

- CMB (more and more a LSS survey), covered by Julian Borrill, Simone Ferraro, Emmanuel Schaan
- Intensity Mapping experiments, covered by Phil Bull

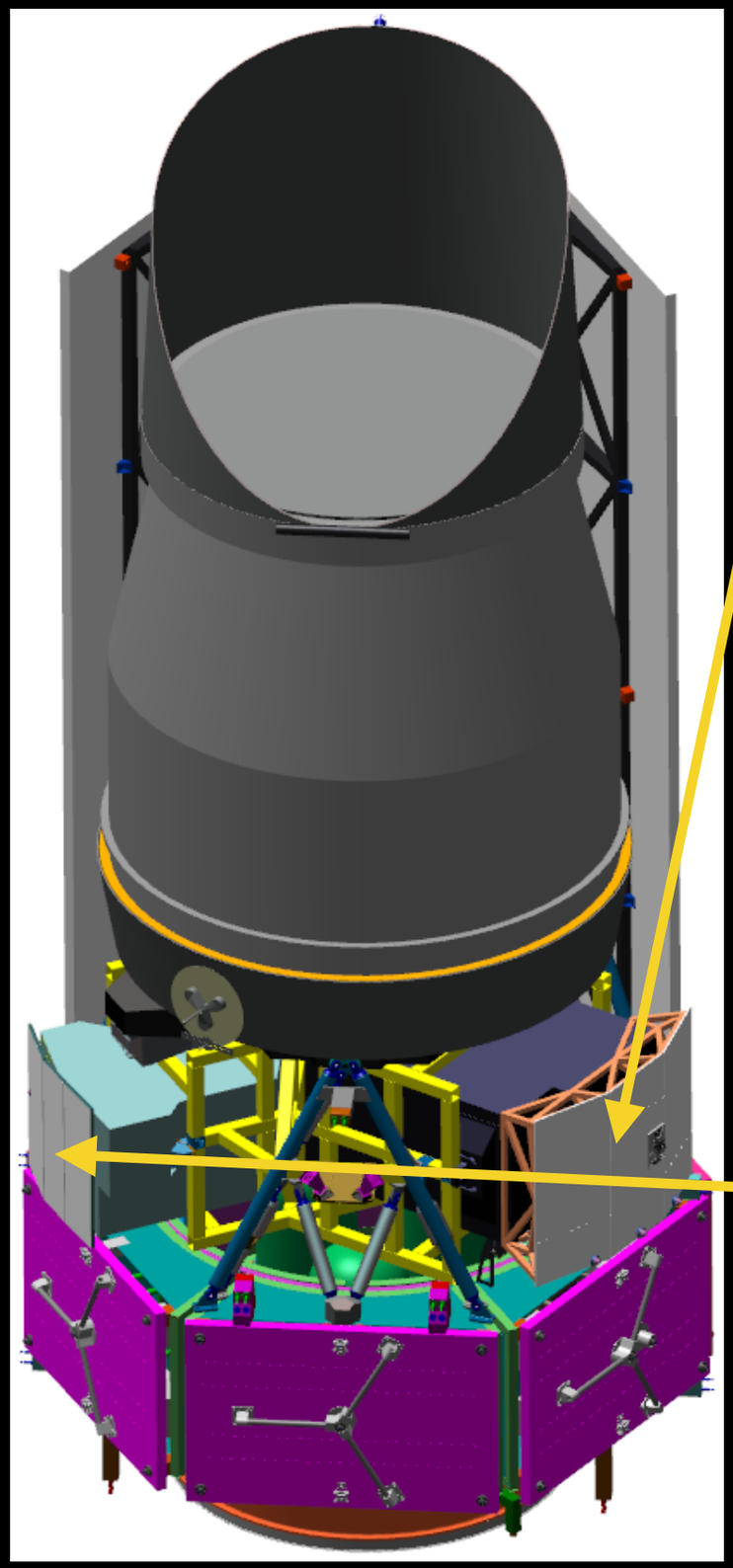
WFIRST

WFIRST: THE NEXT NASA FLASHSHIP

- Top priority from the 2010 Astrophysics Decadal Survey
- Hubble sized telescope, donated by another government agency
- Hubble power and resolution, 100x the field of view
  ➡Hubble quality image over 100x more sky
- Dark energy, exoplanet, and wide-field survey capabilities
- Coronagraph technology to build the “Search for Life” foundation



WFIRST INSTRUMENTS



- Wide-Field Instrument
  - ➡ Imaging & spectroscopy over 1,000s of sq. deg.
  - ➡ Monitoring of SN and micro-lensing fields
  - ➡ 0.7-2.0 μm (imaging), ~1.0-1.93 μm (spec.)
  - ➡ 0.28 deg^2 FoV (100x JWST FoV)
  - ➡ 18 H4RG detectors (288 Mpixels)
  - ➡ 6 filters imaging, 1 grism, 1 prism

- Coronagraph
  - ➡ Image and spectra of exoplanets from super-Earths to giants
  - ➡ Images of debris disks
  - ➡ 430 – 970 nm (imaging) & 600 – 970 nm (IFS spec.)
  - ➡ Final contrast of 10^{-9} or better
  - ➡ Exoplanet images from 0.1 to 1.0 arcsec
  - ➡ *Technology demonstration* for future missions to characterize exo-Earths (e.g., LUVOIR and HabEx)

WFIRST
3 SURVEYS, AN EXPERIMENT, AN OBSERVATORY

- Nominal 5 yr mission

- Three Surveys:
  - ➡ ~2 yrs High-Latitude Survey (HLS)
    - Imaging, spectroscopy

  - ➡ ~6 months SNe search

  - ➡ ~1 yr for repeated galactic bulge observations for micro-lensing

- Experiment:
  - ➡ 1 yr for coronograph

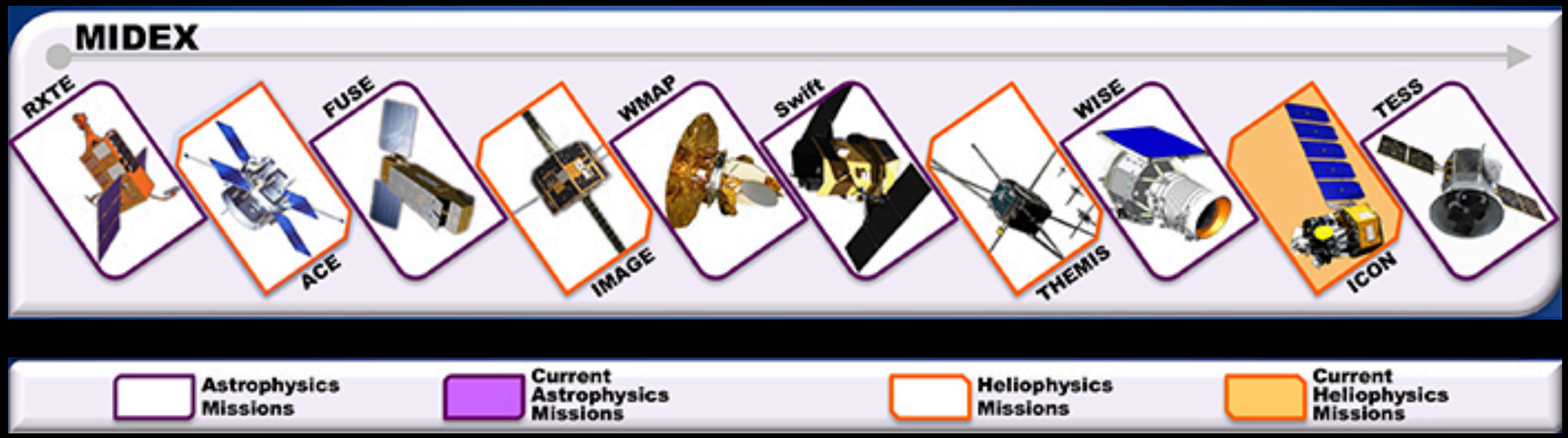
- 25% Guest Observer program

- All data public a few days after they are taken

Akeson++19 arXiv:1902.05569
OD++19 arXiv:1804.03628
OD++19 arXiv:1904.01174

SPHEREX

ASTROPHYSICS & HELIOPHYSICS MID-EXPLORERS MISSIONS



https://explorers.gsfc.nasa.gov/

SPHEREX: AN ALL-SKY SPECTRAL SURVEY

Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer

SPHEREx Dataset:

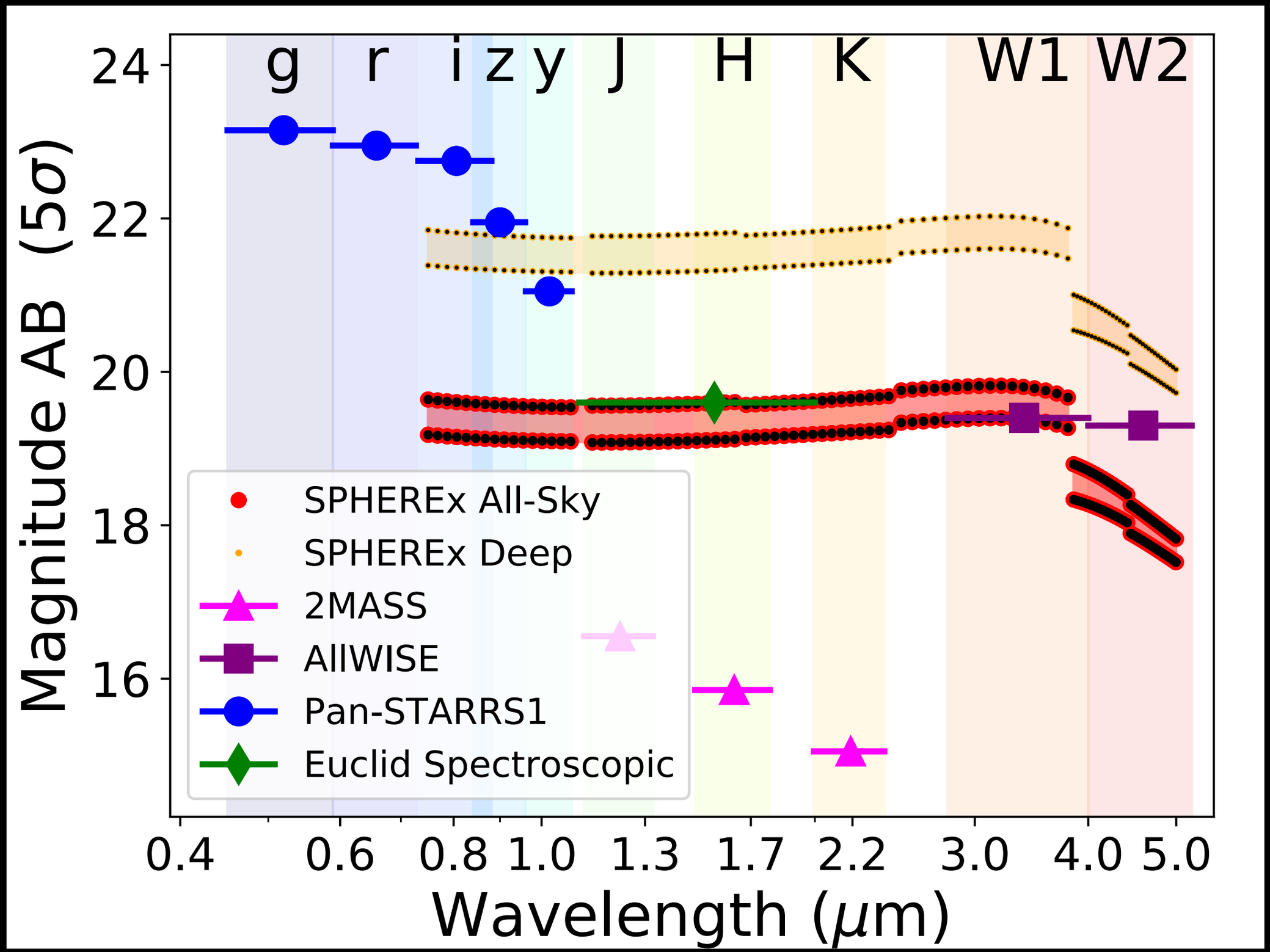
- For every 6.2” pixel over the entire sky:

  ➡ R=35-41 spectra spanning 0.75 μm < λ < 3.82 μm

  ➡ R=110-130 spectra spanning 3.82 μm < λ < 5.0 μm

- ≃ all-sky survey with 96 fine photometric bands

SPHEREX SURVEY DEPTH



Deep survey

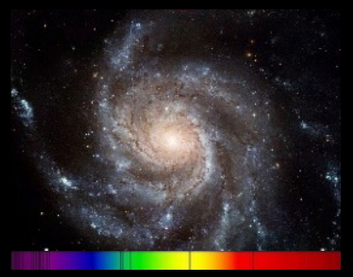
All-sky survey

SPHEREX PROVIDES A RICH ALL-SKY SPECTRAL ARCHIVE

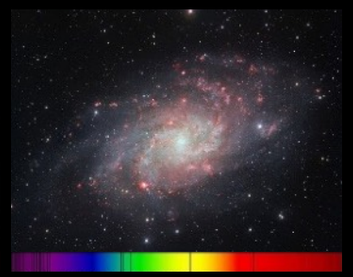
Galaxies

Detected
> 1 billion

Med. Accuracy z's
> 100 million



High Accuracy z's
10 million



Clusters
25,000

Stars

Main Seq. Spectra
> 100 million

Dust-forming
10,000

Brown Dwarfs
> 400

Cataclysms
> 1,000

Other

Quasars
> 1 million

Quasars z >7
3 – 300?

Asteroid Spectra
10,000

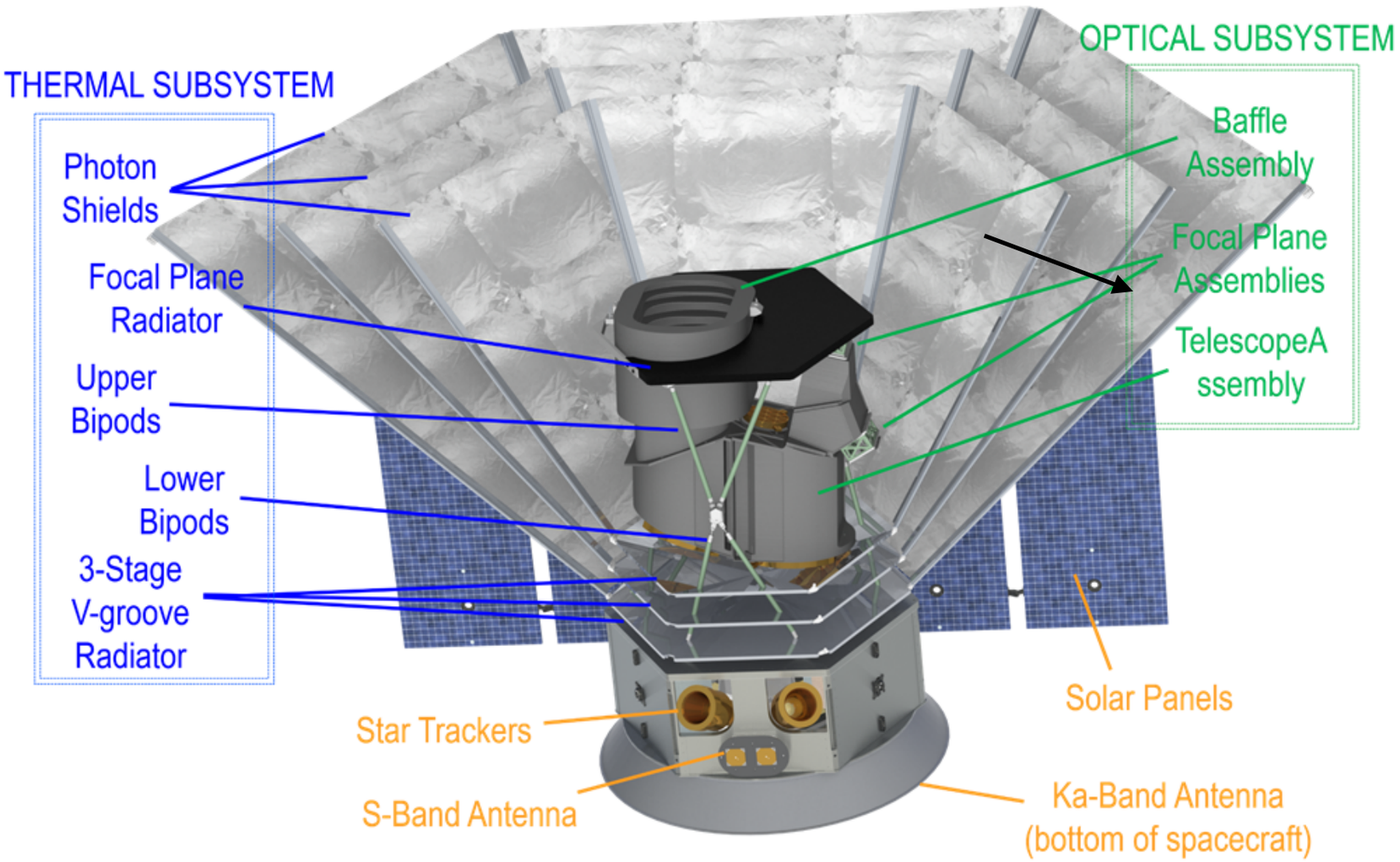
Galactic Line Maps
PAH, HI, H_2

All-Sky surveys demonstrated high scientific returns with a lasting data legacy used across astronomy

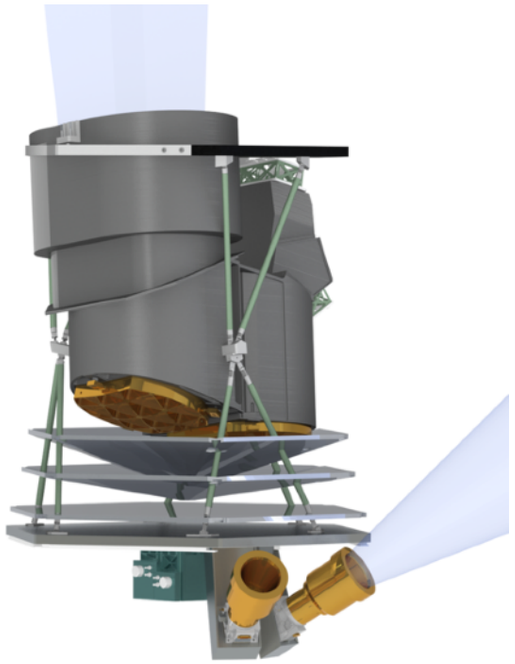
COBE
IRAS
GALEX
WMAP
Planck
WISE

OD++16,18

An Innovative Architecture Based on Mature Technologies

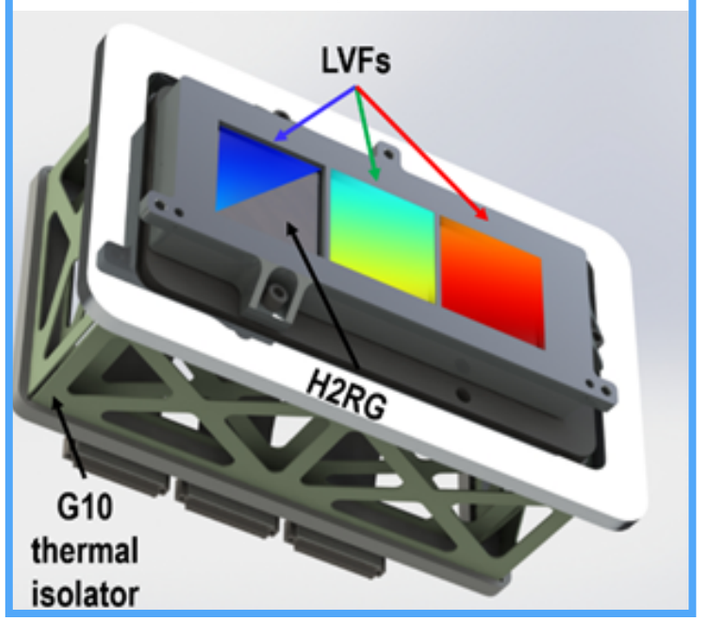


Wide field telescope



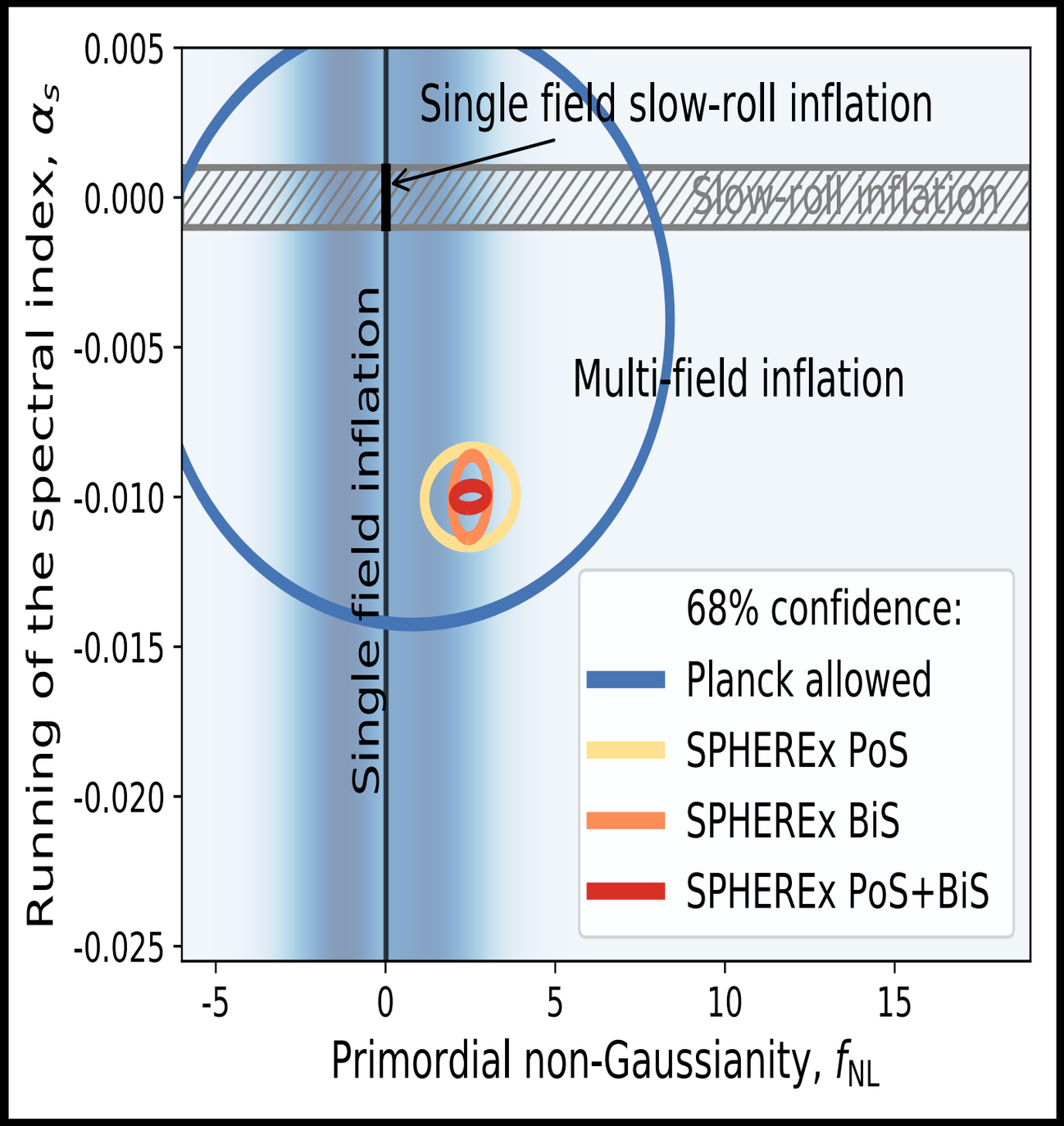
Parameter	Value
Telescope eff. diameter	20 cm
Field of view	3.5 x 11 deg.^{2}
Pixel size	6.2 arcsec
Wavelength range	0.75 – 5 μm
Resolving power $\lambda/\Delta\lambda$	35-130

Compact spectrometer



Pre-Decisional Information
For Planning and Discussion Purposes Only

SPHEREX AND INFLATION



- SPHEREx produces a unique 3-D galaxy survey
  - ➡ Optimized for large scales to study inflation
  - ➡ Two independent tests of non-Gaussianity

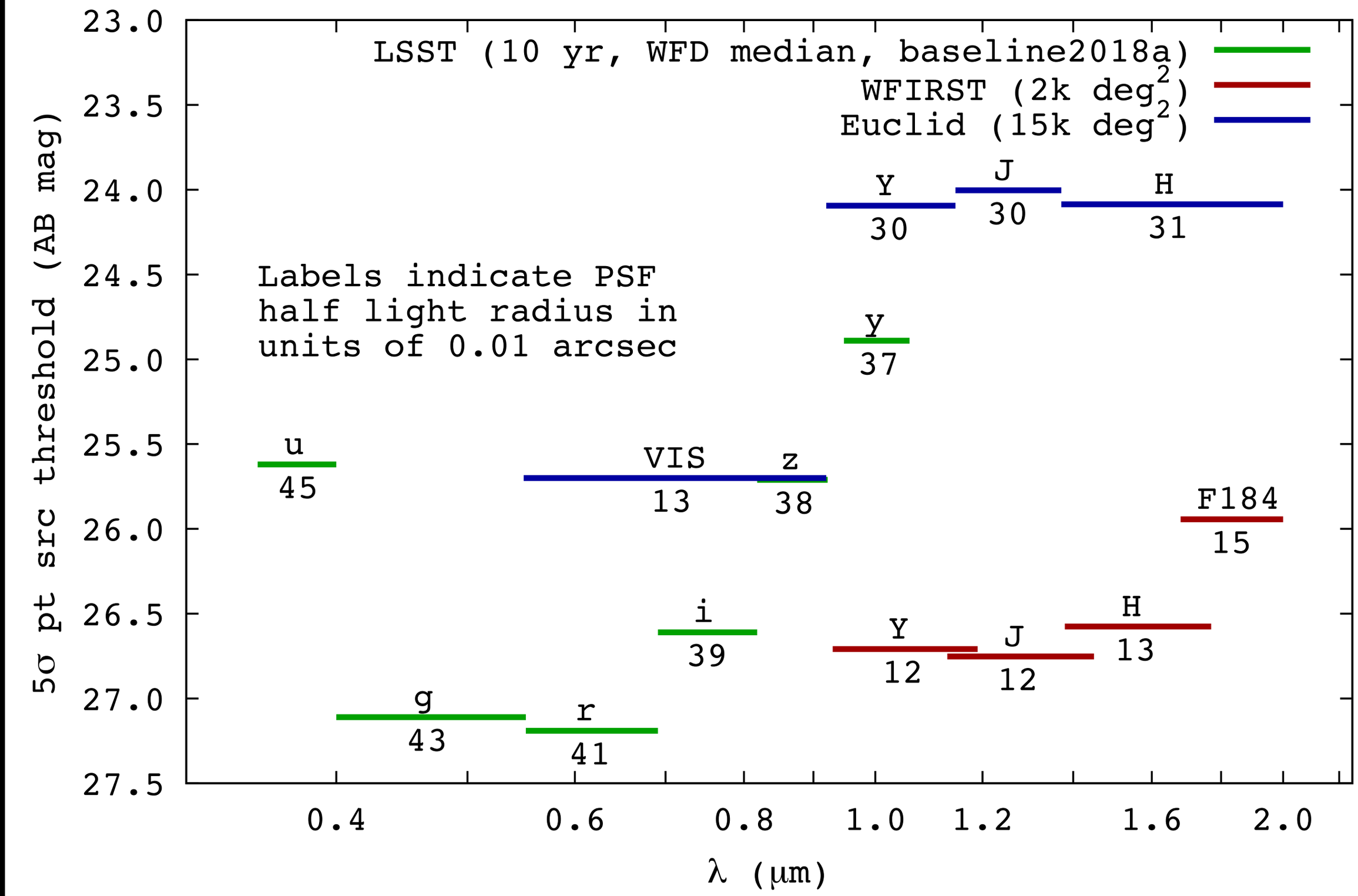
- SPHEREx improves non-Gaussianity accuracy by a factor of ~10
  - ➡ Improves $\Delta f_{NL} \sim 5$ accuracy today to $\Delta f_{NL} < 0.5$

- Discriminates between models
  - ➡ Single-field inflation $f_{NL} << 1$
  - ➡ Multi-field inflation $f_{NL} \gtrsim 1$

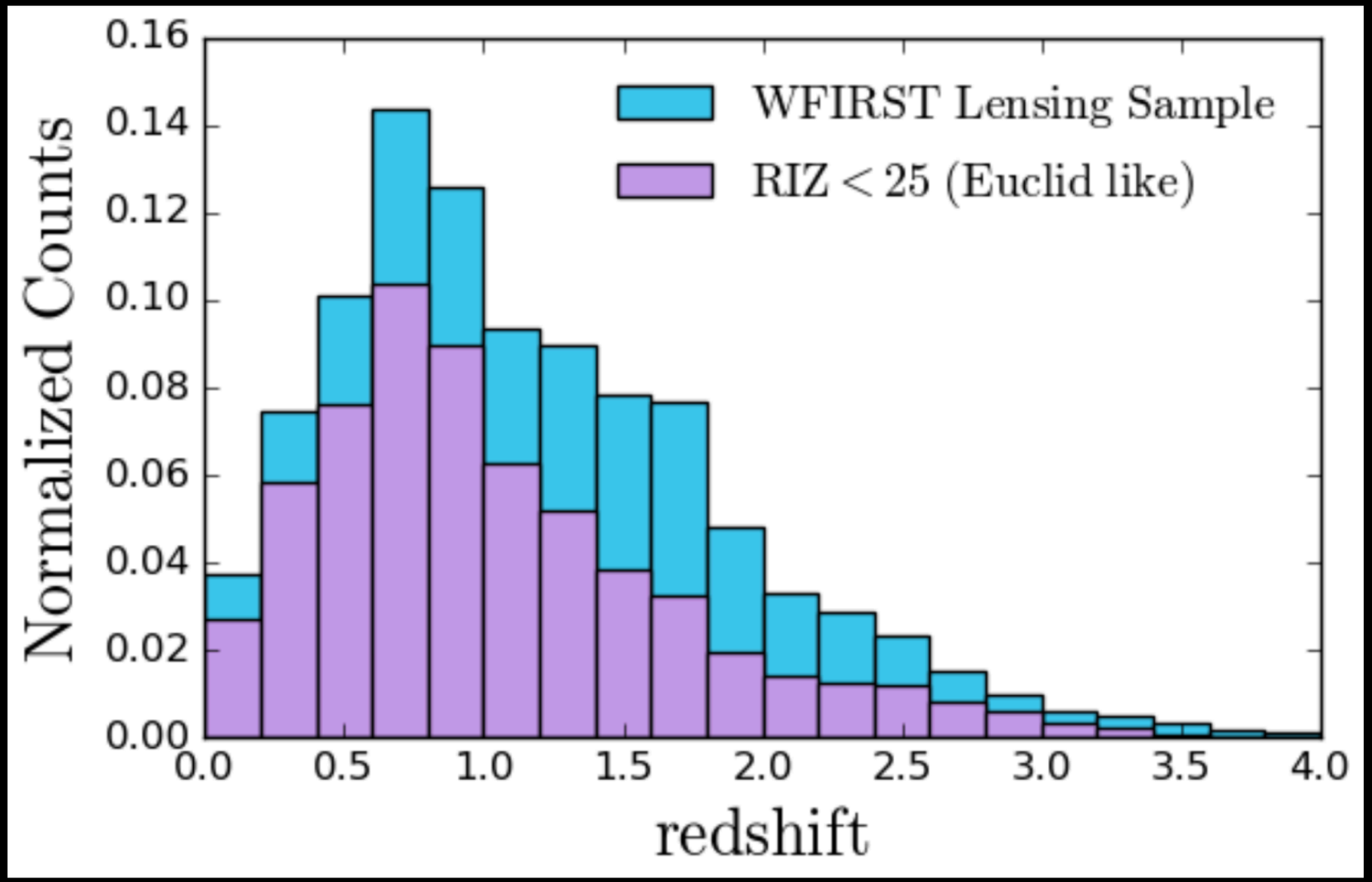
DE SURVEY COMPLEMENTARITY AT A GLANCE

ca. 06/2019	LSST	WFIRST	Euclid	DESI
Start, duration	2022, 10 yr	~2025, 5 (-10) yr	2022, 6 yr	2019, 5 yr
Cosmo Area (sq. deg.)	14,300 (S+N)	~2,000 (S)	15,000 (S+N)	14,000 (N)
FOV (sq. deg.)	10	0.28	0.53	7.9
Eff. diameter (m.)	6.7	2.2	1.1	3.3
FWHM (arcsec.)	0.81	0.18	0.15 (VIS) 0.3-0.6 (NIR)	
Pixel (arcsec.)	0.2	0.11	0.1 (VIS), 0.3 (NIR)	
Photometric Survey	6 bands (u,g,r,i,z,y)	4 bands (Y,J,H,F184)	4 bands (VIS,Y,J,H)	
Photometric Galaxies (w/ shapes) (#/arcmin^2)	~26 in 2 bands (r,i)	~50 in 3 bands (J,H,F184)	~30 in 1 band (VIS)	
Pass / field	~400	6 (2/band)	1	
SN1a	10^5 - 5x10^5 z=0.05-1.1 photometric	2,7x10^3-2x10^4 (IM) z=0.15-2.0 Prism spectroscopy		
Spectroscopic Survey		Grism R=550-800 1-1.93 μm	Grism R>~380 1.25-1.85 μm	Fibers R=2000–5500 0.36-0.98 μm
Spectroscopic Galaxies		ELGs z=0.52-1.94 Hα (~20M) z=1.0-2.85 [OIII] (~5M)	ELGs z=0.9-1.8 Hα (~30M)	LRGs+ELGs z=0.6-1.7 (20-30M) QSOs/Lyα 1.9<z<4 (1M)

WFIRST, EUCLID, AND LSST SENSITIVITIES



SOURCE DENSITIES

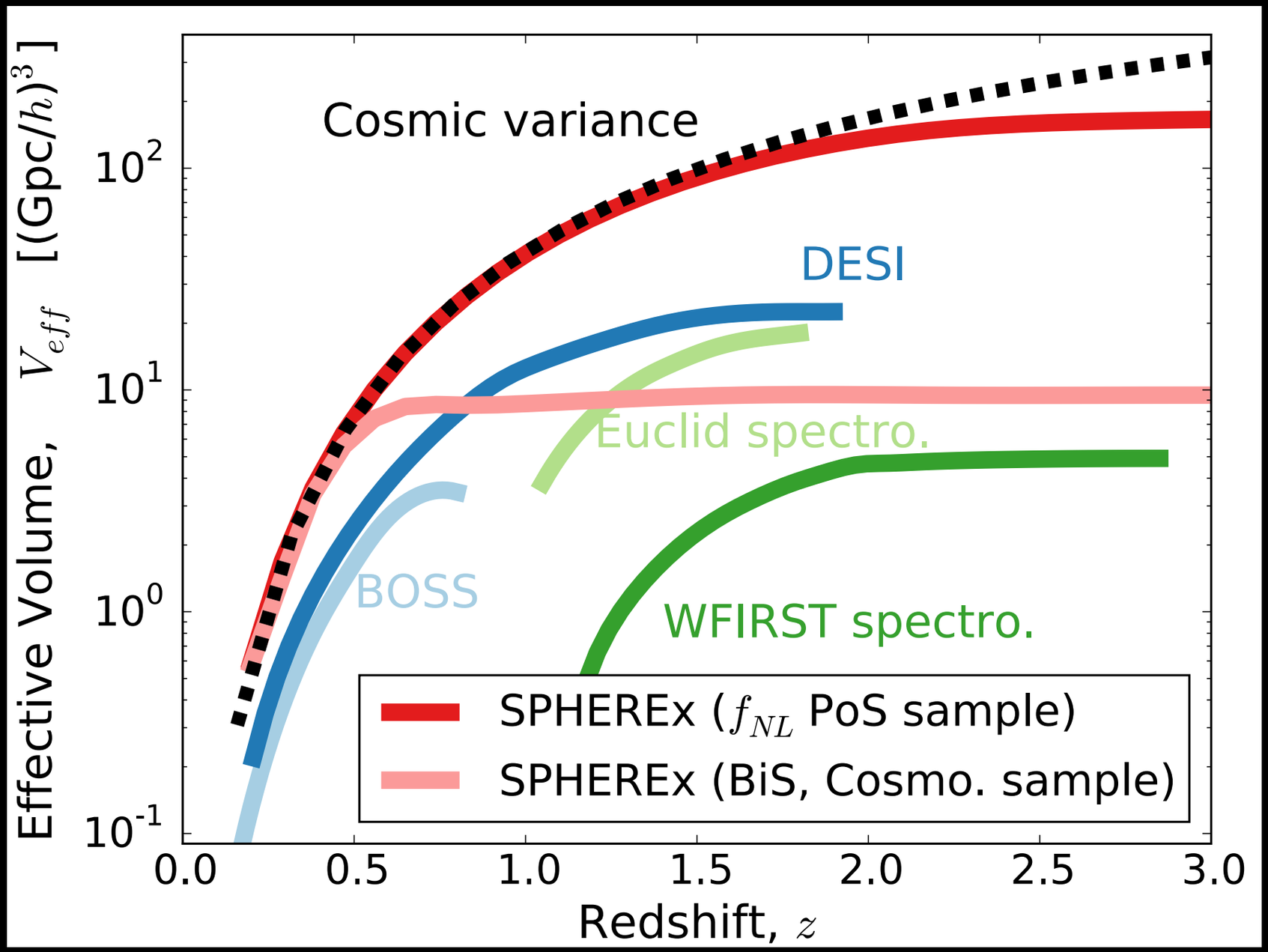


- Based on CANDLES data

Shoubaneh Hemmati++19

EFFECTIVE VOLUME FOR SPECTRO SURVEYS

$$V_{eff} = \left(\frac{P_{gal}}{P_{gal} + 1/n_{gal}} \right)^2 V_{phys}$$



(k=0.01 h/Mpc)

(k=0.2 h/Mpc)

- Mind the different spectral resolution Stickley++16

THE WHOLE IS GREATER THAN THE SUM OF ITS PARTS

- Multiple cosmological surveys will enable multiple cosmological probes, which will enable a robust physical interpretation
  - ➡The decade of “multi-probe” analysis

- Multiple surveys will enable important and critical cross-checks
  - ➡New insights on the nature of DE will be thoroughly cross-validated

- Joint analysis have strong mutual benefits:
  - ➡Systematics control (see *Elisabeth Krause* talk)
  - ➡Novel cosmological signals
  - ➡Already strong cross-survey planning, e.g. on deep fields

- The decade of MOUs!

e.g. Jain++15

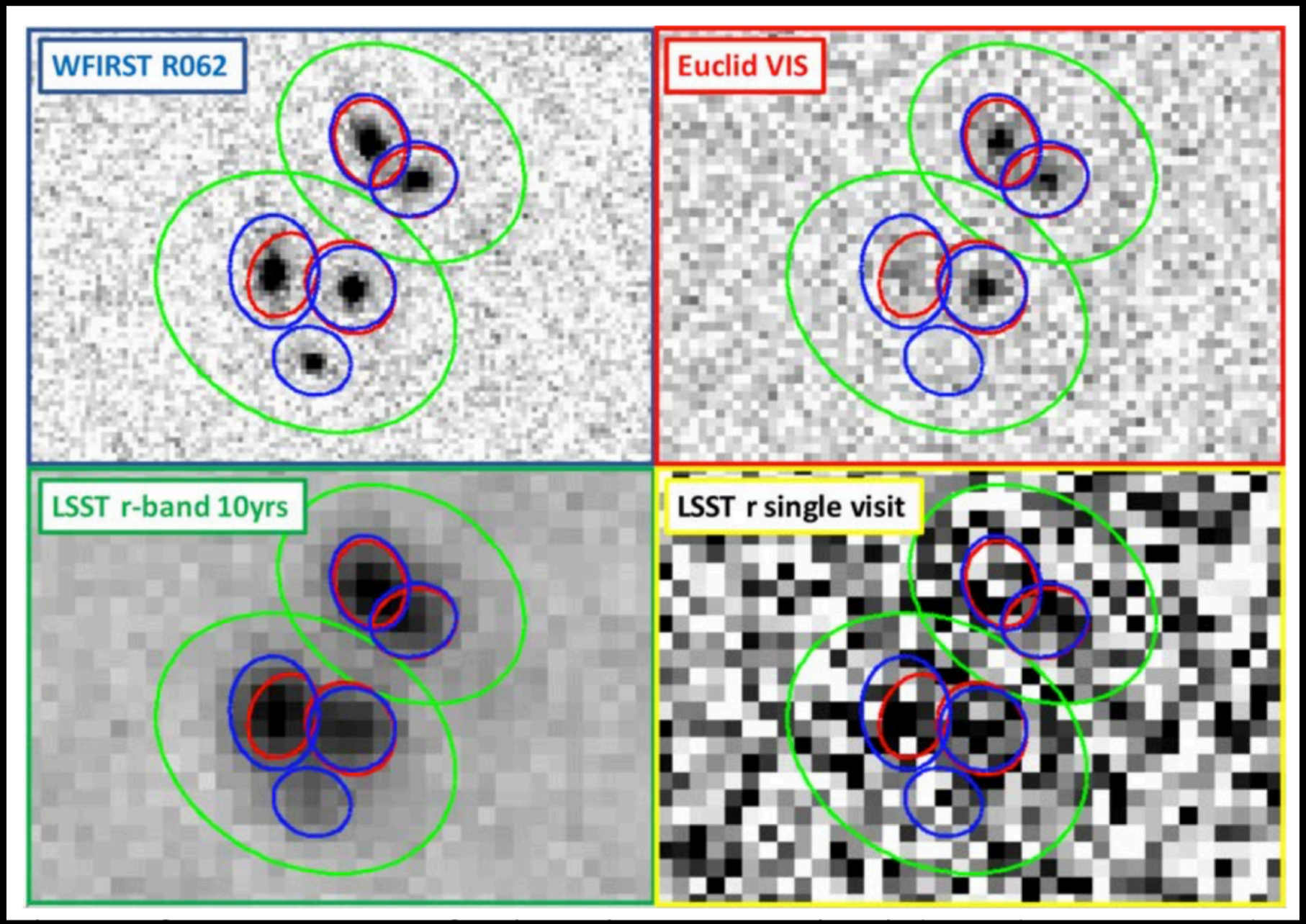
LSST AND WFIRST (/EUCLID) - I

- Photometric redshift:
  - ➡ WFIRST does not cover the Balmer/4000A break at low z
  - ➡ WFIRST needs LSST

- Cross-correlations:
  - ➡ WFIRST spectro. survey to calibrate LSST photo-z using clustering-redshift
    - Especially true at z ≥ 1.5 where the ground-based ELG samples tail off.
  - ➡ WFIRST [OIIII] sample is ideal between 1.02<z<2.85 and 2.55 denser than DESI QSOs at z>1.5

- Shape measurement validation:
  - ➡ WFIRST observations help LSST WL with calibration of the shear estimates
  - ➡ WFIRST PSF correction smaller and well characterized
    - ~nm-level wavefront stability available in space and extensive calibration program planned for detector effects, e.g., cross-talk, reciprocity failure

BLENDING SURVEYS TO DEBLEND SOURCES



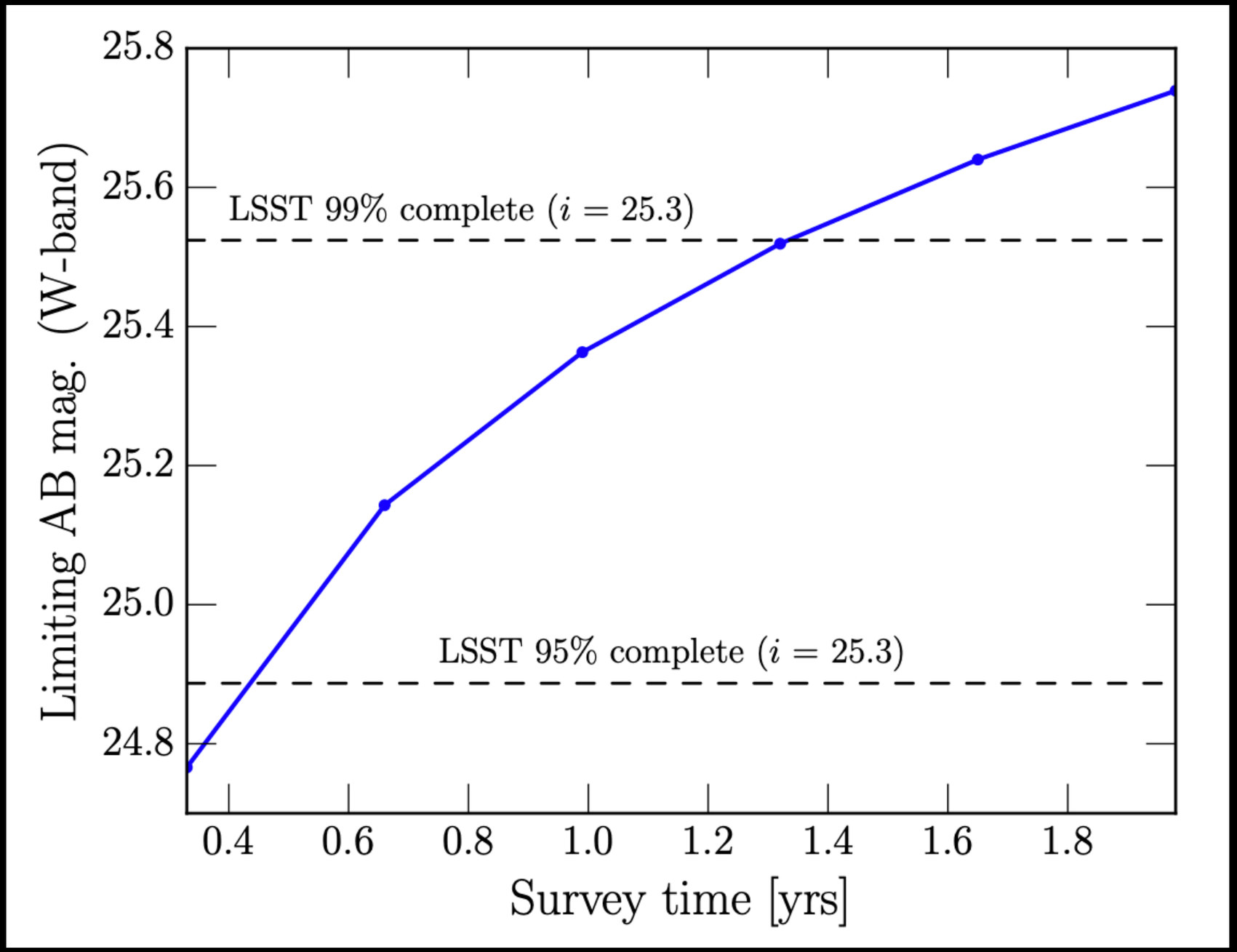
WFIRST R

Euclid VIS

LSST r

courtesy of Bomee Lee, 2019 Joint Survey Processing report

WFIRST W BAND LARGE AREA SURVEY



Eifler, Heinrich, Krause, Miyatake, Simet et al., 2019, *in prep*.

EUCLID/WFIRST/LSST AND SPHEREX

- Cosmology:
  - ➡SPHEREx-detected galaxies generally lower-z than Euclid, enabling complementary science
  - ➡SPHEREx galactic extinction map will help photo-z systematics
  - ➡Stacking of faint isolated SPHEREx sources produce representative object SEDs (Padmanabhan++18)
  - ➡Photo-z calibration in deep fields (Ilbert, Salvato 19)
  - ➡SPHEREx ideal for finding QSOs and isolated dusty galaxies

- Calibration
  - ➡Direct calibration of Euclid images and spectra on large spatial scales
  - ➡Directly tie all four parts of the Euclid survey to the same spectro-photometric system

THE WHOLE COSMOGOLD IS GREATER THAN THE SUM OF ITS PARTS

- The coming decade is going to be transformative:
  - ➡Multiple ground-breaking surveys are planned
  - ➡DESI, LSST, Euclid, SPHEREx, WFIRST

- Multiple cosmological surveys will enable multiple cosmological probes, which will enable a robust physical interpretation

- Multiple surveys will enable important and critical cross-checks

- Very strong mutual benefits in joint analysis and interpretations

- Scientific discoveries are guaranteed.
  - ➡How fundamental will they be?

FIN